



## First Synthetic Nanomotor

A team led by Berkeley Lab physicist Alex Zettl has created the first nanosized electric motor. The motor consists of a 300 nm gold rotor on a carbon nanotube shaft; it is the smallest synthetic motor ever reported. Key team members included graduate students Adam Fennimore and Tom Yuzvinsky.

The creation of smaller and smaller moving components, such as motors, is an important goal in the growing field of nanoscience. There have been dramatic advances in the miniaturization of both mechanical and electromechanical devices. Commercial microelectromechanical systems now reach the submillimeter to micrometer size scale, and there is intense interest in the creation of next-generation synthetic nanometer-scale electromechanical systems (NEMS). It appears that efforts to scale down existing microelectromechanical systems (MEMS) to the nanoscale may be unsatisfactory due to dominant surface effects in this Si-based technology. In this context, the unusual mechanical and electronic properties of carbon and boron-nitride nanotubes (including favorable elastic modulus and tensile strength, high thermal and electrical conductivity, and low inter-shell friction of the atomically smooth surfaces, cf. MSD Highlights 00-5 and 00-9) may be useful in developing practical NEMS devices.

Indeed, multiwalled nanotubes (MWNTs) are an essential component of this first successful NEMS device. The team deposited MWNTs on the surface of a silicon wafer and selected individual tubes with an atomic force microscope. A gold rotor, nanotube anchors, and opposing stators (stationary parts of the motor) were then simultaneously patterned around the chosen nanotubes using electron beam lithography. A third stator was already buried under the silicon oxide surface. Part of the surface was then etched to provide sufficient clearance for the rotor. With a sufficiently strong electrical voltage applied to the stators, the rotor could be caused to torque the outer shell of the MWNT past their elastic limit, thus selectively shearing the outer nanotube shell and creating a MWNT rotational bearing. Subsequently, the rotor could be made to rotate on its nanotube shaft and enclosed atomically-smooth bearing (see figure). With small (<5V) voltages applied to the stators, the motor could be rotationally operated for many thousands of cycles, with no apparent wear or degradation in performance. In this configuration, the MWNT clearly serves as a reliable, presumably wear-free, NEMS element providing rotational freedom.

These MWNT-based nanomotors or actuators have obvious MEMS/NEMS applications potential. The rotational metal plate could serve as a mirror, with obvious relevance to ultra-high-density optical sweeping and switching devices (the total actuator size is just at the limit of visible light focusing). The rotating plate could also serve as a paddle for inducing and/or detecting fluid motion in microfluidics systems, as a gated catalyst in wet chemistry reactions, as a bio-mechanical element in biological systems, or as a general (potentially chemically functionalized) sensor element. Using methods to align nanotubes, it should be possible to fabricate arrays of orientationally ordered nanotube-based actuators on substrates.

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A. M. Fennimore, T. D. Yuzvinsky, Wei-Qiang Han, M. S. Fuhrer, J. Cumings, and A. Zettl, "Rotational actuators based on carbon nanotubes," *Nature* **424**, 408 (2003).

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